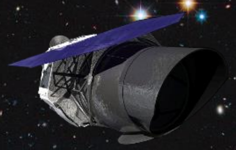
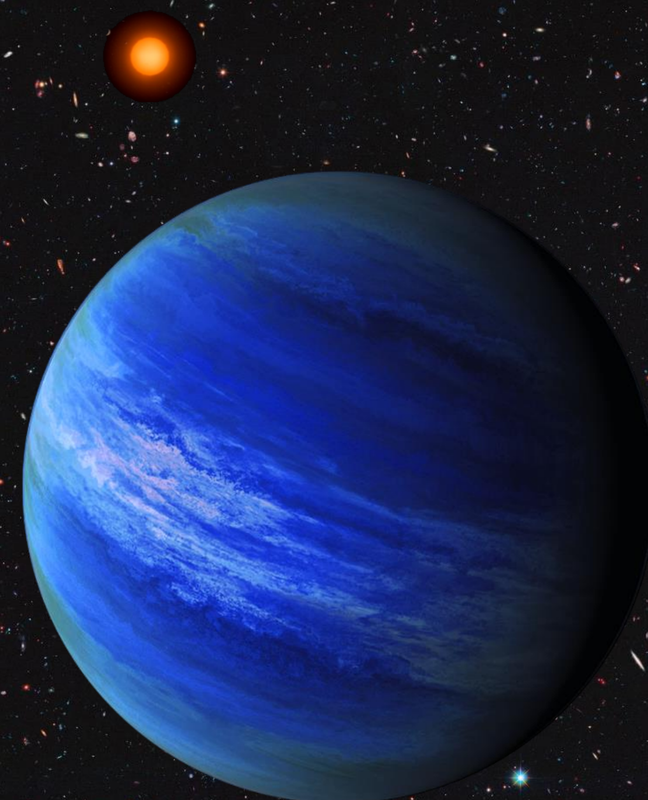


Review & Update of WFIRST Coronagraph Instrument & Technology



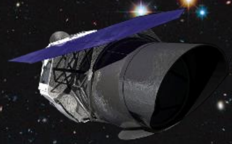
Richard Demers & CGI Team

SPIE Conference 10698-89

Optical, IR & Millimeter Wave

15 June 2018

Jet Propulsion Laboratory
California Institute of Technology



Co-authors

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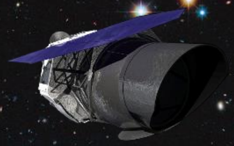
1 Jet Propulsion Laboratory, California Institute of Technology
2 NASA Goddard Space Flight Center



Instrument Status & Overview

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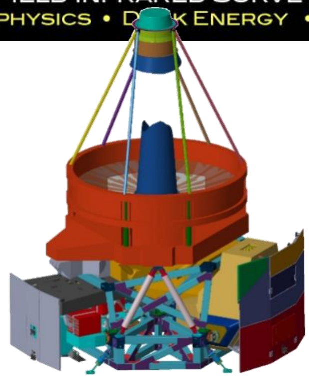
California Institute of Technology

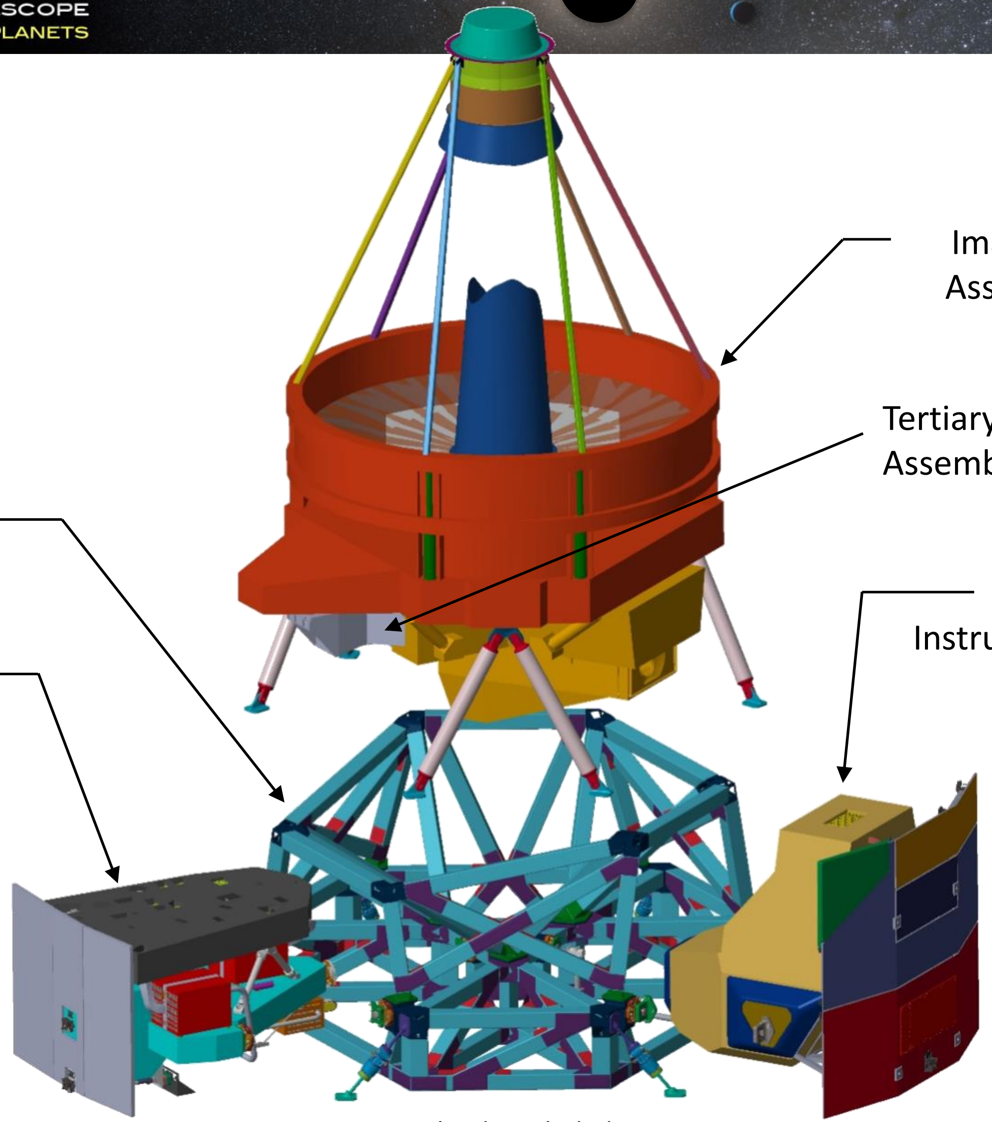
SRR/SDR Summary, 1 of 2

- SRR/SDR held on 8,9 May 2018 at JPL
- Independent Review Team (IRT) drawn from various institutions
  - Carnegie Institute, Chair
  - JPL
  - NASA HQ, GSFC
  - Caltech
  - GMTO
- "The IRT deems the CGI…sufficiently mature to proceed to project life cycle Phase B and Preliminary Design Review (PDR)"
- 29 Requests for Action (RFAs) "but none of them presents an objection to the project moving forward to Phase B
- "…the CGI team has met and addressed all of the multiple success criteria listed for a SRR/SDR, and that as a result the WFIRST CGI is ready to begin Phase B."

CGI in WFIRST Payload

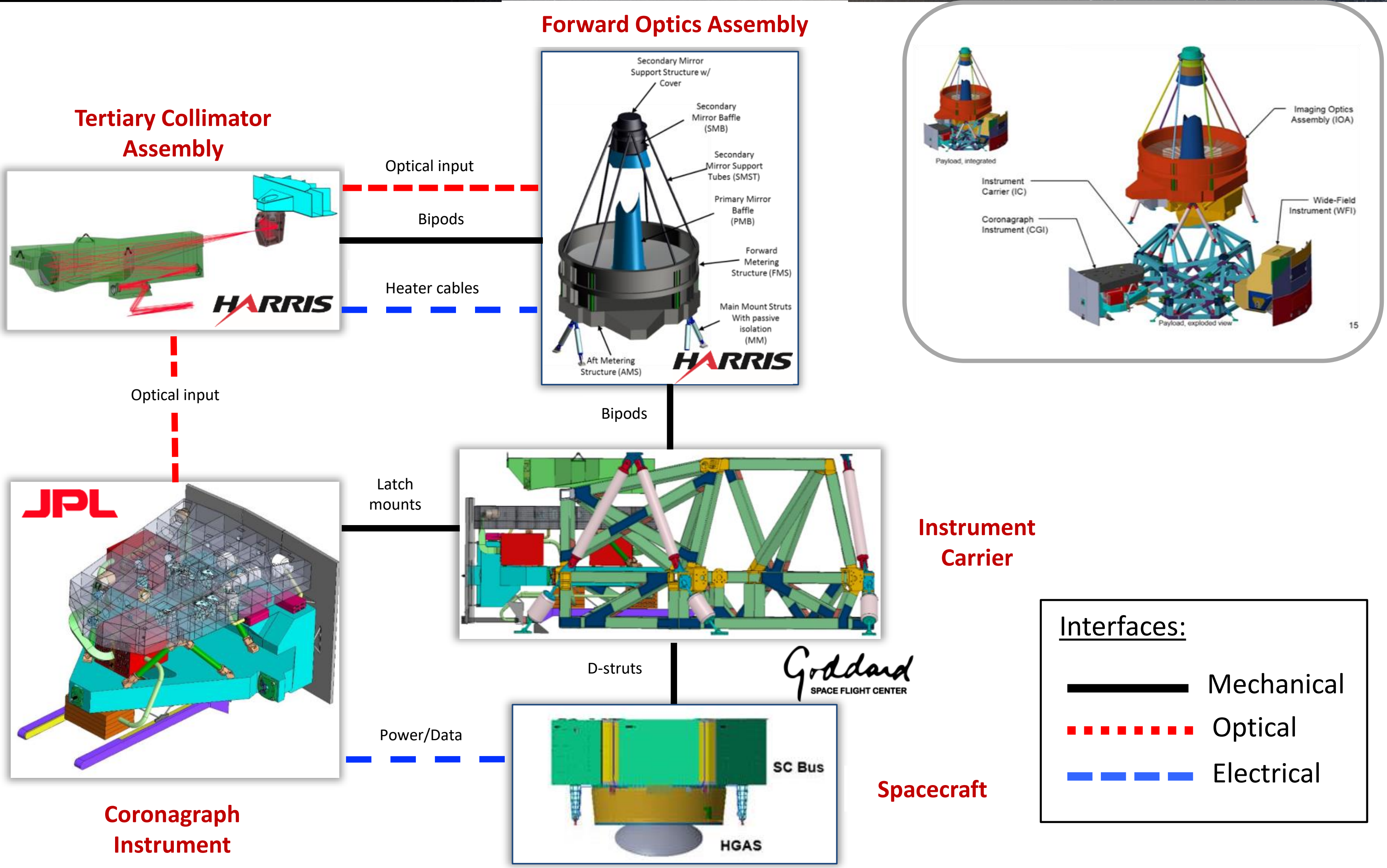


Payload, integrated



Payload, exploded view

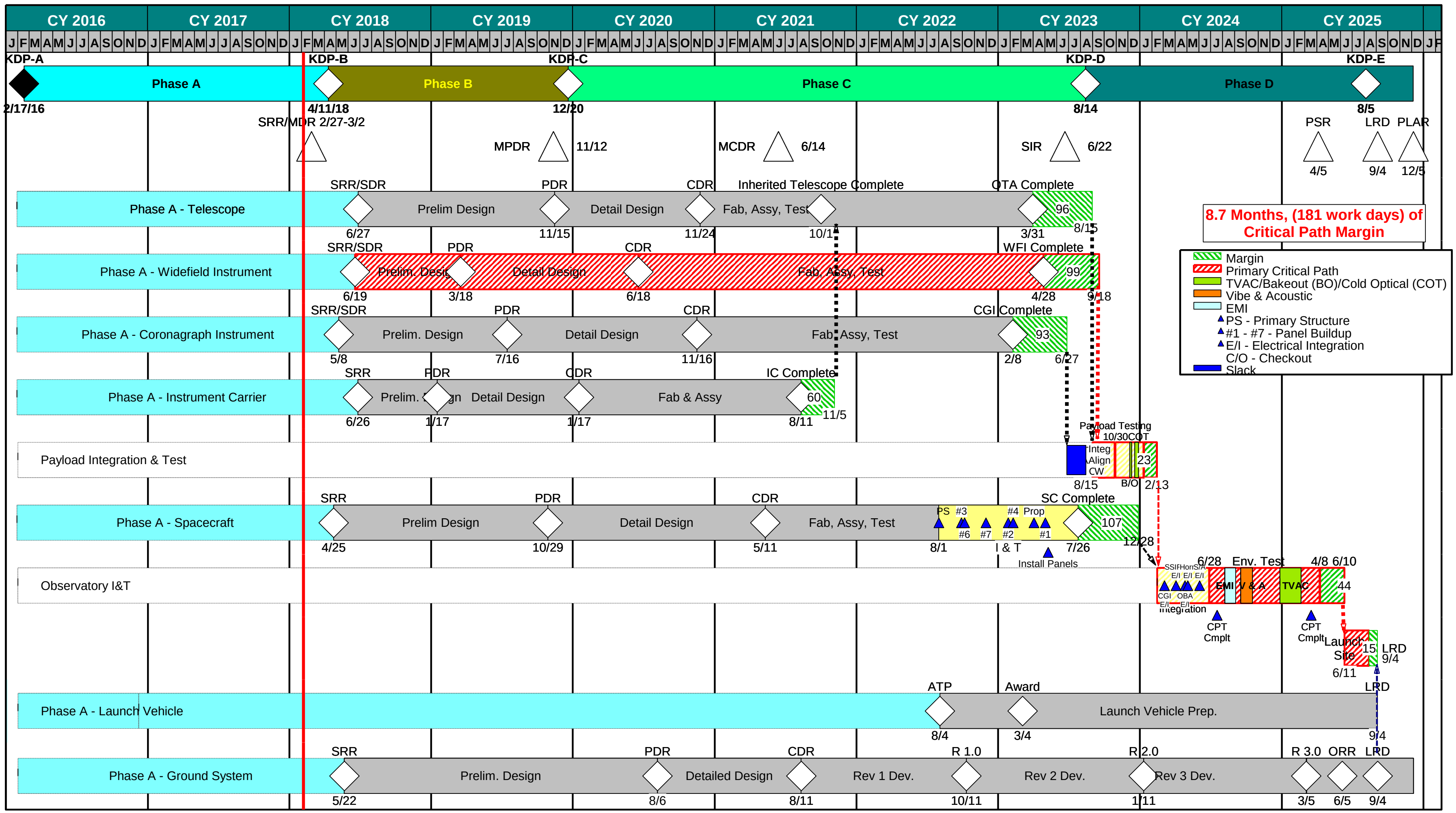
CGI External Interfaces

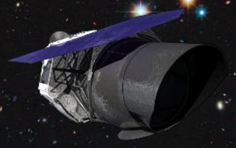


WFIRST Mission Schedule

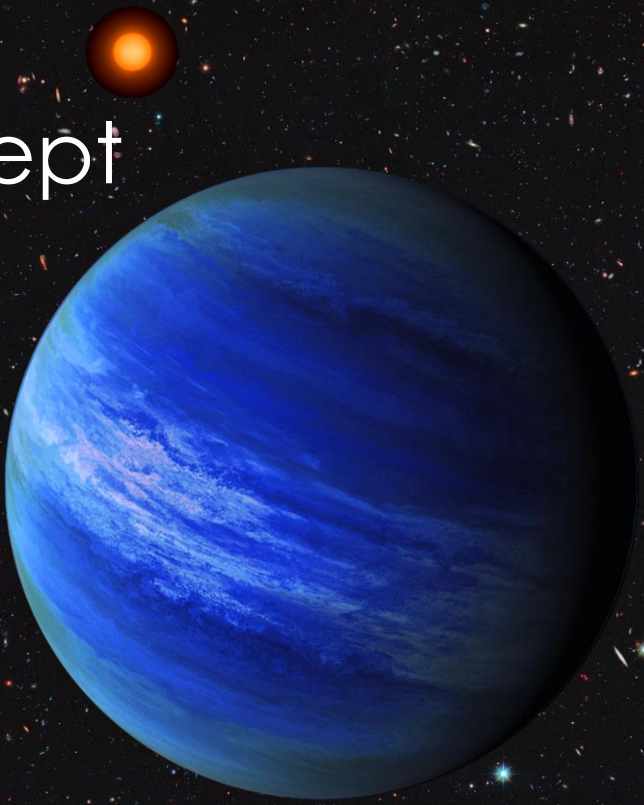
Preliminary WFIRST Development Schedule
POST WIETR

2/5/2018





Coronagraph Design Concept



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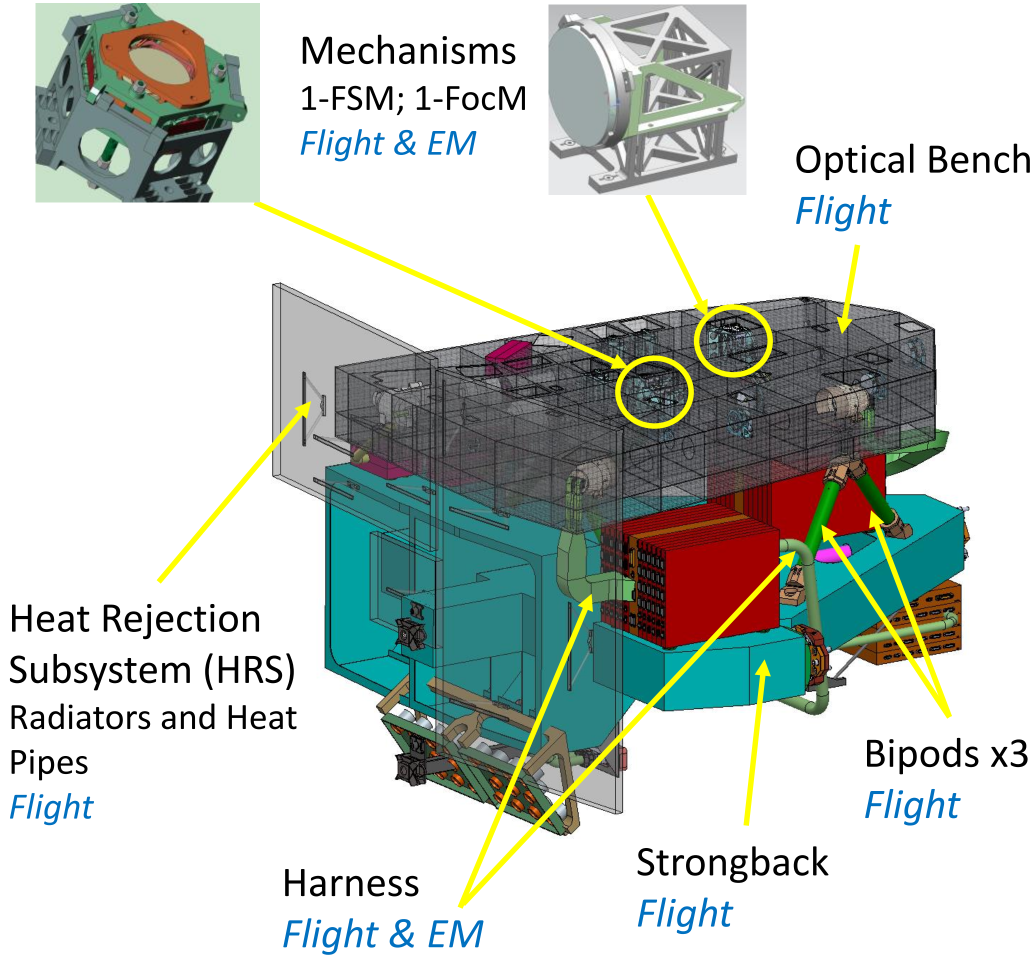
CGI Overview

- 2 PbMgNb Deformable Mirrors (48x48 actuators)
- Direct Imaging channel with Photon-Counting EMCCD operated at 165 K
- Integral Field Spectrograph (R = 50, cooled EMCCD camera)
- Low-Order Wavefront Sensor (Rejected starlight, EMCCD camera)
- Passively cooled electronics and EMCCDs
- Active thermal control for bench, DM, EMCCDs and electronics
- Robotically serviceable payload interface
- Starshade accommodation



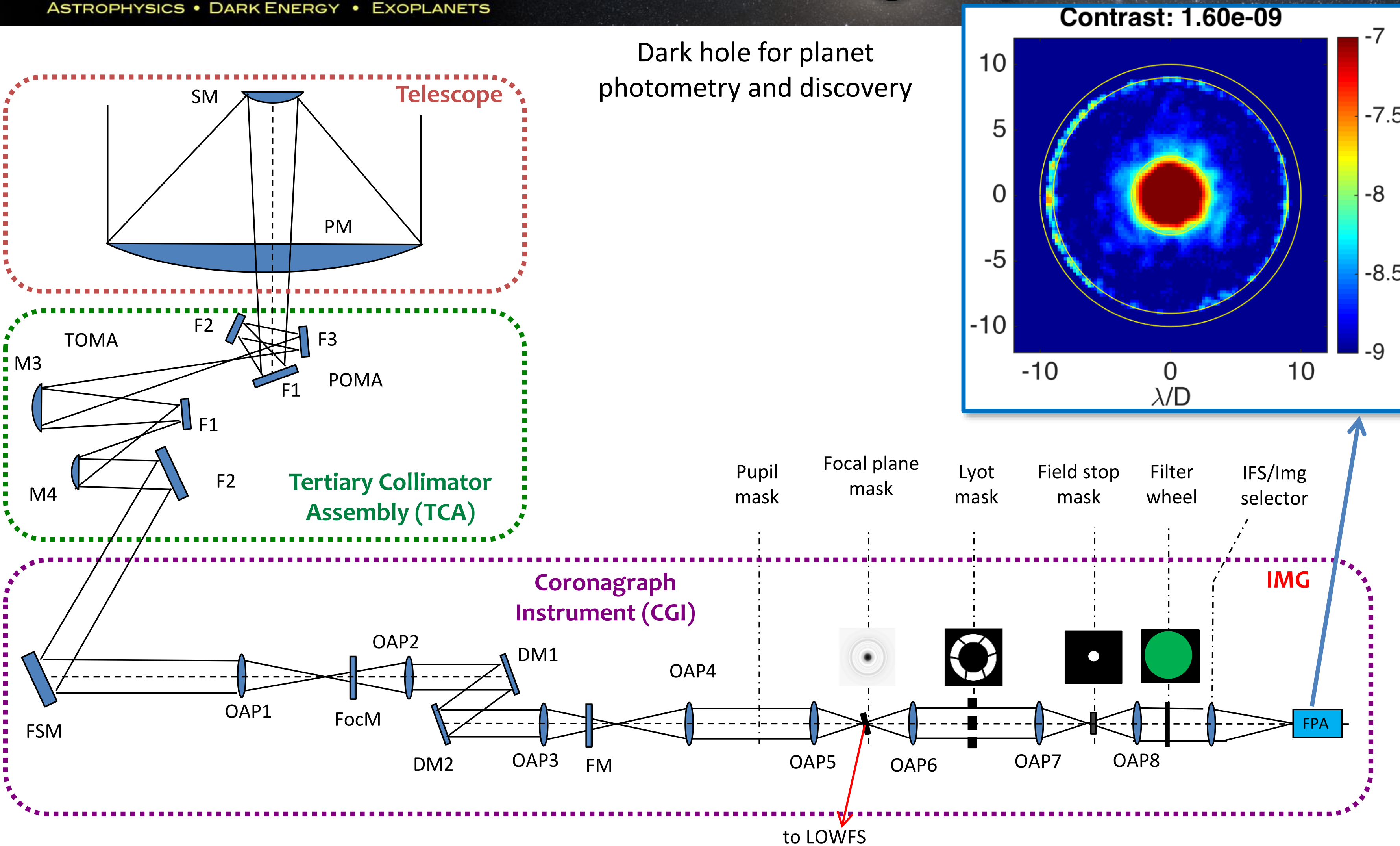
Thermal HW not shown:
Heaters/PRTs/Tstats/Thermal Straps/MLI

Structure & Harness
- **CBE 83.9kg**

Thermal Hardware
- **CBE 25.7kg**

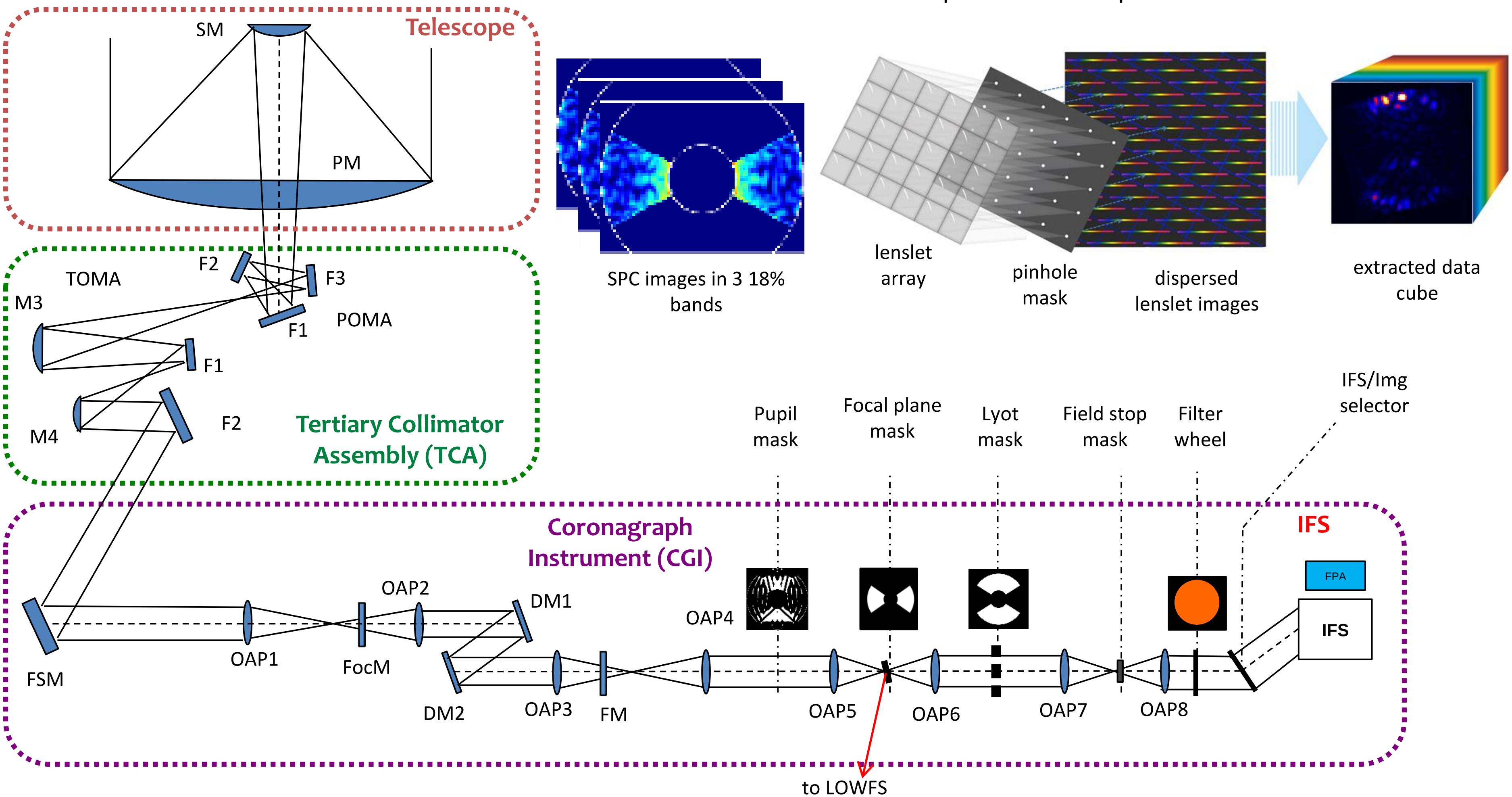
Imaging with Narrow Field of View Mode

Dark hole for planet photometry and discovery



Spectroscopy Mode

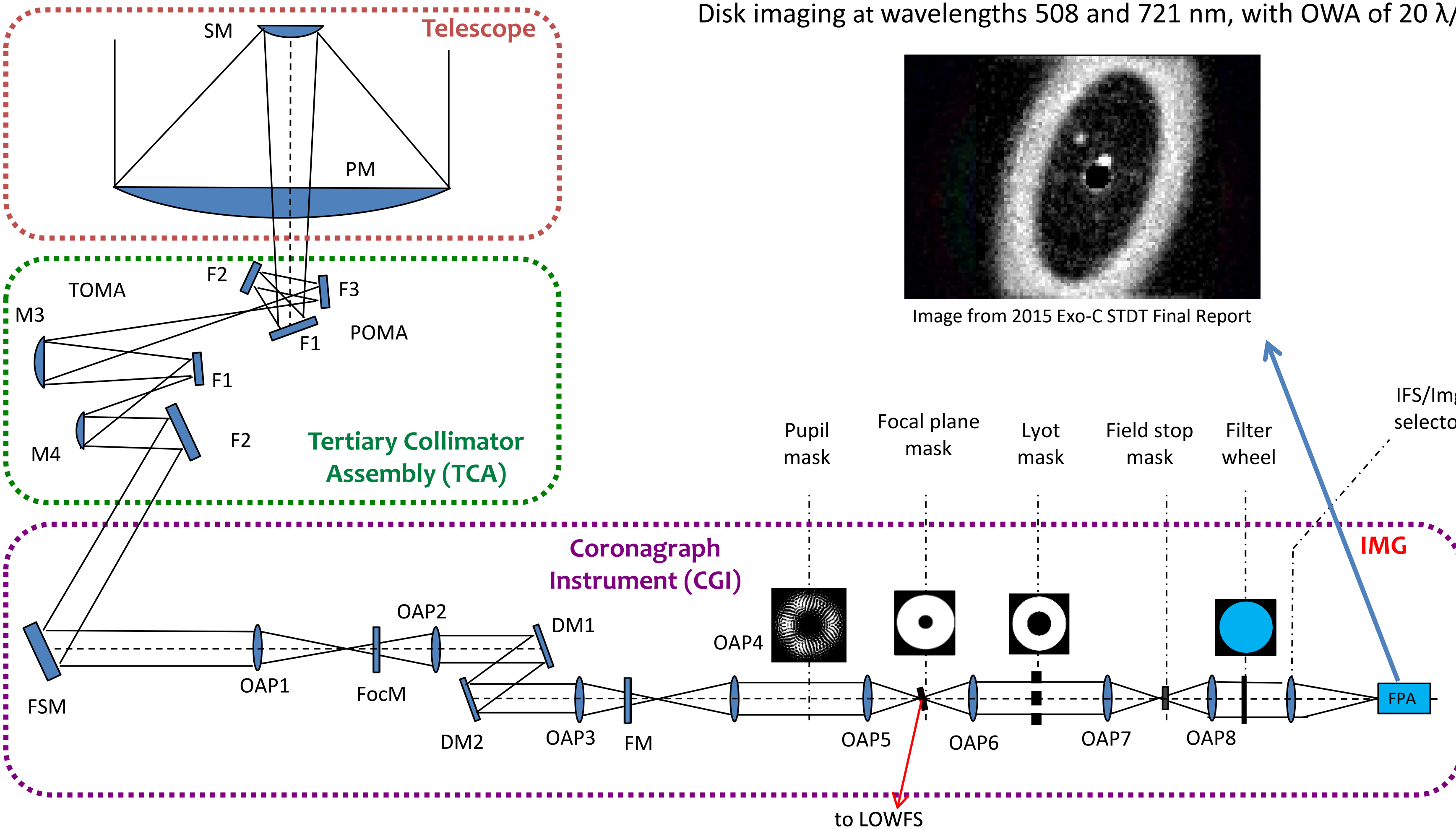
The IFS uses 3 18% bands to produce R=50 spectra from 600 to 970nm

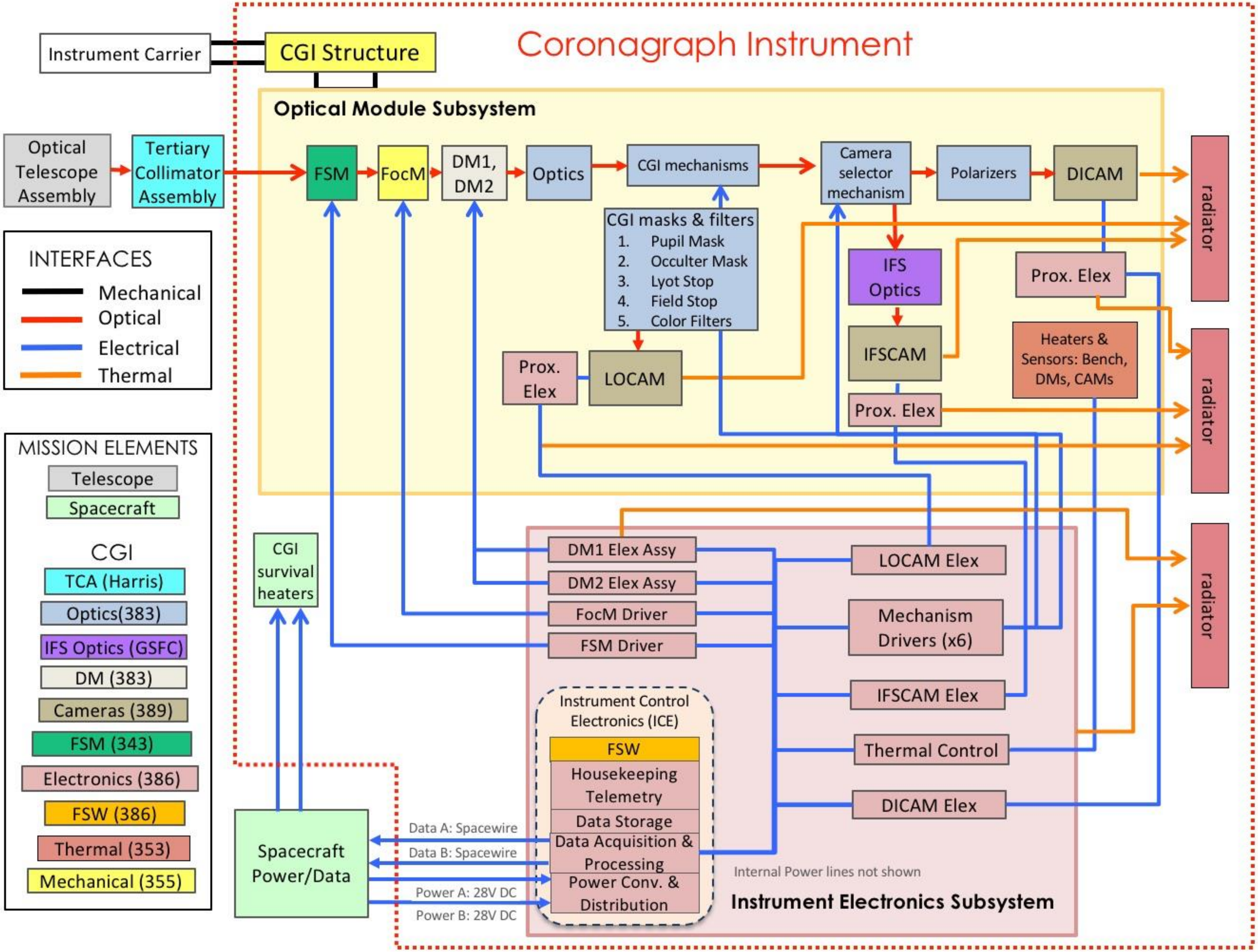


Imaging with Wide Field of View Mode

Disk imaging at wavelengths 508 and 721 nm, with OWA of 20 λ/D

Image from 2015 Exo-C STDT Final Report

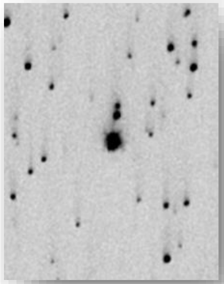




Coronagraph Instrument
Instrument Carrier
CGI Structure
Optical Module Subsystem
Optical Telescope Assembly
Tertiary Collimator Assembly
FSM
FocM
DM1, DM2
Optics
CGI mechanisms
Camera selector mechanism
Polarizers
DICAM
radiator
CGI masks & filters
1. Pupil Mask
2. Occulter Mask
3. Lyot Stop
4. Field Stop
5. Color Filters
IFS Optics
Prox. Elex
IFSCAM
Heaters & Sensors: Bench, DMs, CAMs
Prox. Elex
LOCAM
Prox. Elex
radiator
radiator
INTERFACES
Mechanical
Optical
Electrical
Thermal
MISSION ELEMENTS
Telescope
Spacecraft
CGI
TCA (Harris)
Optics(383)
IFS Optics (GSFC)
DM (383)
Cameras (389)
FSM (343)
Electronics (386)
FSW (386)
Thermal (353)
Mechanical (355)
CGI survival heaters
DM1 Elex Assy
DM2 Elex Assy
FocM Driver
FSM Driver
LOCAM Elex
Mechanism Drivers (x6)
IFSCAM Elex
Thermal Control
DICAM Elex
Instrument Control Electronics (ICE)
FSW
Housekeeping Telemetry
Data Storage
Data Acquisition & Processing
Power Conv. & Distribution
Spacecraft Power/Data
Data A: Spacewire
Data B: Spacewire
Power A: 28V DC
Power B: 28V DC
Internal Power lines not shown
Instrument Electronics Subsystem

Low Flux Detector

- The Teledyne-e2v EMCCD (CCD201-20) used for Imaging, Spectroscopy and Low Order Wavefront Sensing
- Design/process variants are under evaluation to
  - Improve performance margins for CGI technology demonstration
  - Maximize performance for future exoplanet missions
- Image degradation in photon counting mode due to radiation induced traps & cosmic rays
- Variants under evaluation to mitigate traps and cosmic ray tails

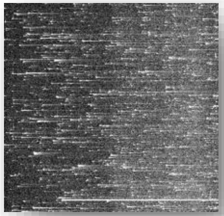


<u>Process change only</u>

1. Visible light shield removed – improves image via less transfers

<u>Design changes</u>

1. 4 & 3 μm narrow channel – improves image via lower trap capture rate
2. Notch channel – improves image via lower trap capture rate
   - Has more heritage than narrow channel
3. Low noise output amplifier & gain register overspill – mitigates cosmic ray tails



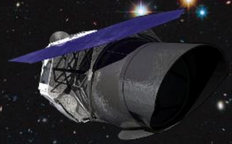
- Downselect between options April 2019

Selection of best EMCCD design for improved rad hardness

Instrument Processing Architecture

- Implementation of demonstrated algorithms in flight processing hardware
- Instrument Processor architecture
  - LEON4 processor + Virtex-5QV FPGA
    - HOWFSC
    - CGI command & control
  - Virtex-5QV FPGA
    - LOWFSC
- Key tasks for Phase B
  - Implement HOWFS Jacobian matrix processing (FFTs) in the FPGA
  - Use existing JPL boards to run benchmark tests
    - Run FFTs (Jacobian processing) in FPGA
    - Compare implementation of non-FFT portion of algorithms in LEON4 vs (LEON4 + FPGA)
    - Verify estimates for knockdown factors used in the processing calculations
  - Evaluate RTG4 FPGA as alternate to Virtex-5

Optimization of algorithms/processing across processor and FPGA(s) using existing flight designs/parts



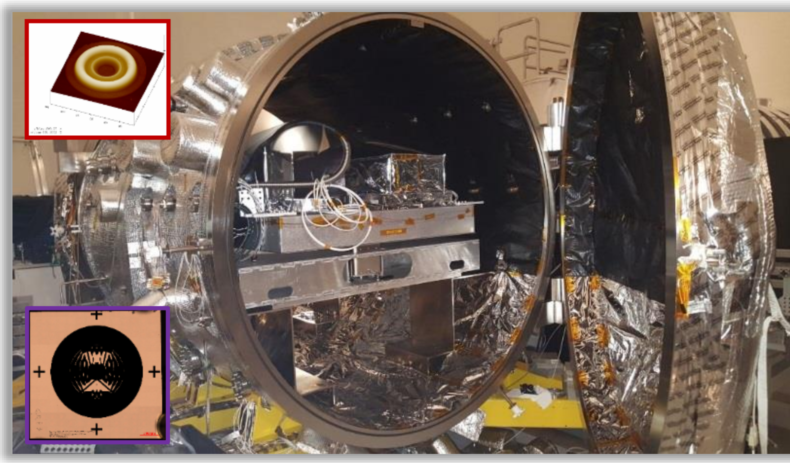
Technology Development & Engineering Risk Reduction

Technology Testbed

- LOWFS/C performance has been tested using source brightness equivalent to stars in the flight like condition (Mv ≤ 5.0).
- With WFIRST like line-of-sight jitter injected by the testbed's Jitter Mirror the LOWFS/C can maintain the contrast stability for source as faint as Mv = 5. The post correction residual jitter, measured by coronagraph contrast, has shown to meet the WFIRST jitter requirement of 0.5 mas.
- Using source equivalent to Mv = 5 the testbed measured focus error rejection matches model prediction very well for LOWFS/C low order (focus) correction loop using a DM.
- We have also demonstrated simultaneous starlight light suppression wavefront control (EFC) while LOWFS/C is correcting the injected WFIRST like line-of-sight and wavefront disturbances, which will be reported in the next talk.
- Future work on the testbed for LOWFS/C:
  - Testing with low flux source continues on OMC testbed.
  - Integrating an existing integral field spectrometer (IFS) to the OMC testbed to demonstrate CGI spectroscopy mode working with LOWFS/C under dynamic condition.
  - Updating OTA-Simulator which includes updated jitter mirror and pinhole relay optics which will provide more capability of dynamic wavefront test

Engineering Testbed

- Technology testbed facility will be repurposed to an engineering testbed after CGI PDR
- Unique system level validation vehicle
  - End-to-end system level testing
  - FSW testing
  - Verification of technology infusion (mask design, algorithms)
- Leverages an existing facility and several years of CGI testbed operations experience
- OTA simulator enables injection of dynamic disturbances
  - Thermal drift and RWA jitter
- Will use flight-like configuration
  - EM assemblies
  - Flight processor and electronics
  - Mechanisms
  - Cameras & DMs

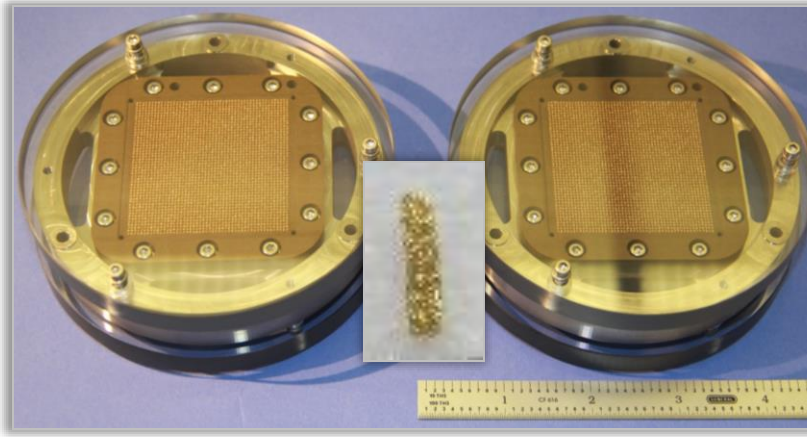


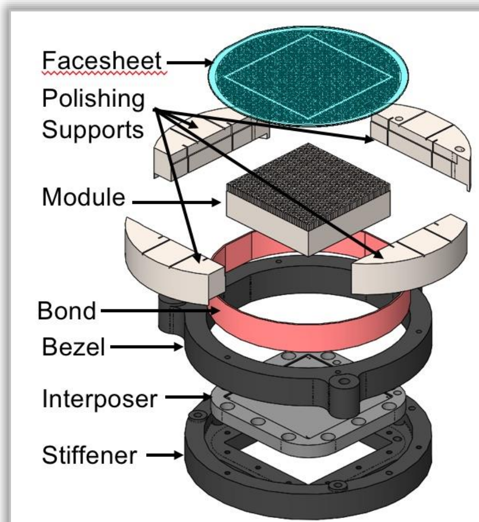
Deformable Mirror

NORTHROP GRUMMAN

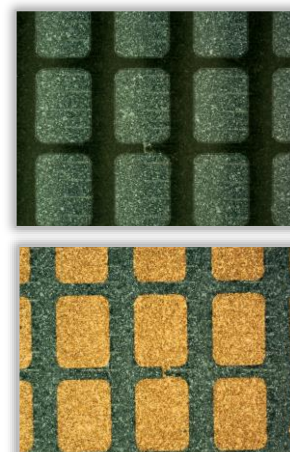
- PbMgNb (PMN) Electrostrictive DM
- with fuzz button interconnect
- Flight Interconnect development
  - Baseline: Reworkable Fuzz button interconnect
  - Backup: Micro-coil spring interconnect
  - Evaluate performance using Vacuum Surface Gauge & environmental testing
  - Downselect among two options Jan 2019 & begin 2nd build
- Module Connector-side Metallization
  - Photoresist used to eliminate conductive coupling between neighboring metal pads during deposition
- Environmental testing in 2018
  - Random vibration & thermal cycling

DM Advancing to TRL-6





Photoresist pads (above)
Metallized pads (below)



Summary

- SRR/SDR and gate products successfully completed
- CGI now in Phase B
- Staffing has begun to ramp up
- Funds have been shifted forward from FY19,20 to FY18 to reduce schedule risk
- CGI team is poised to accelerate progress
- Instrument PDR summer 2019

DARE
MIGHTY
THINGS

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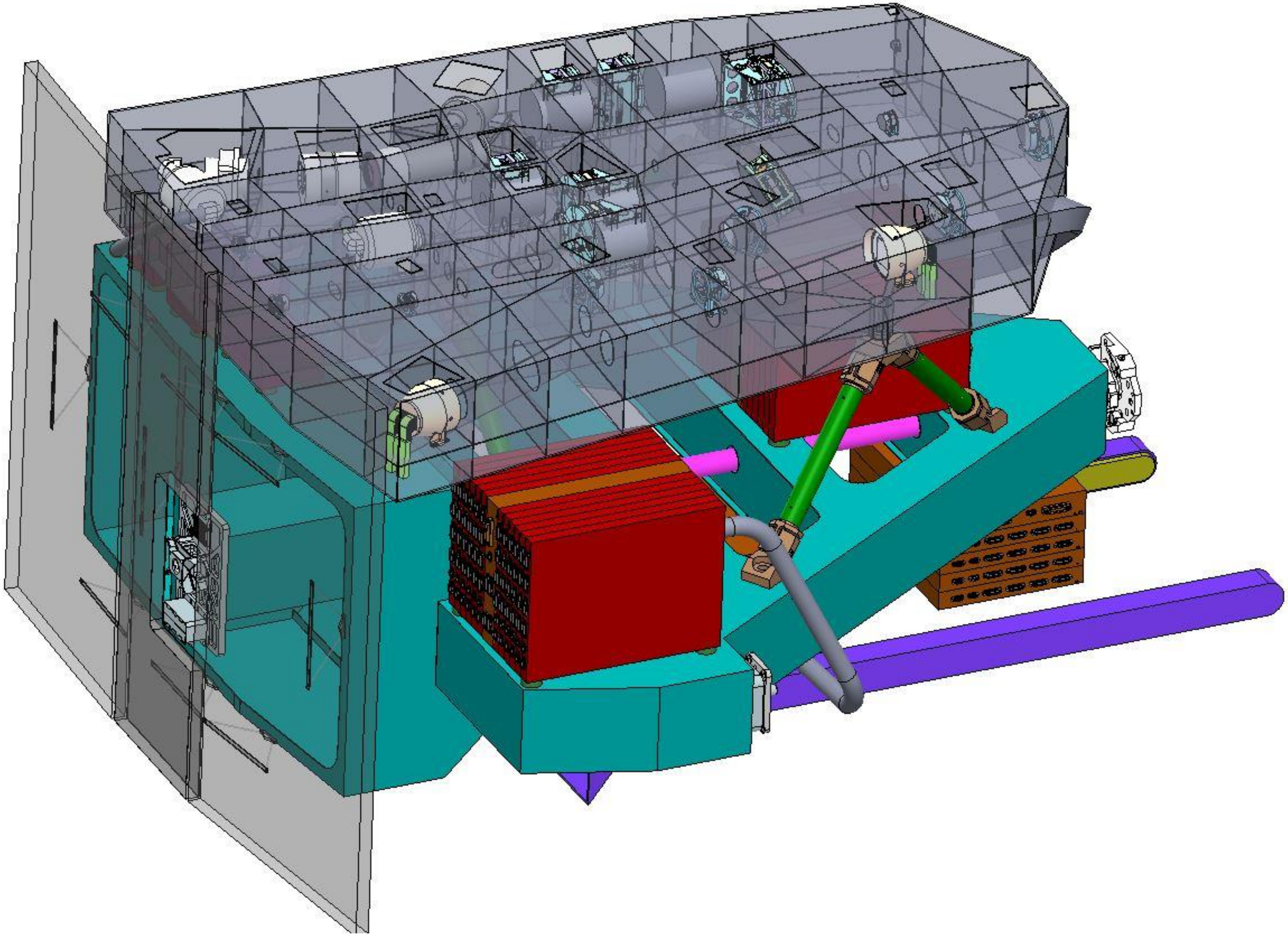
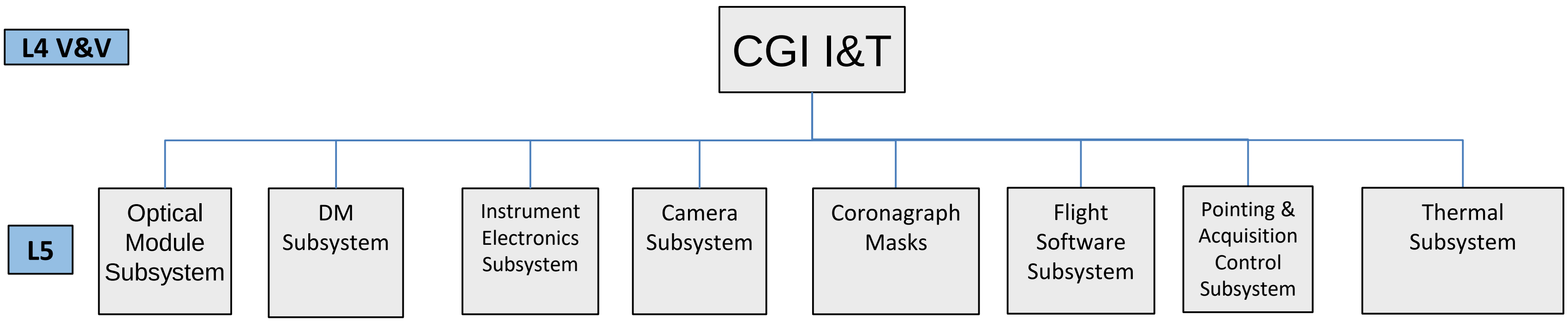
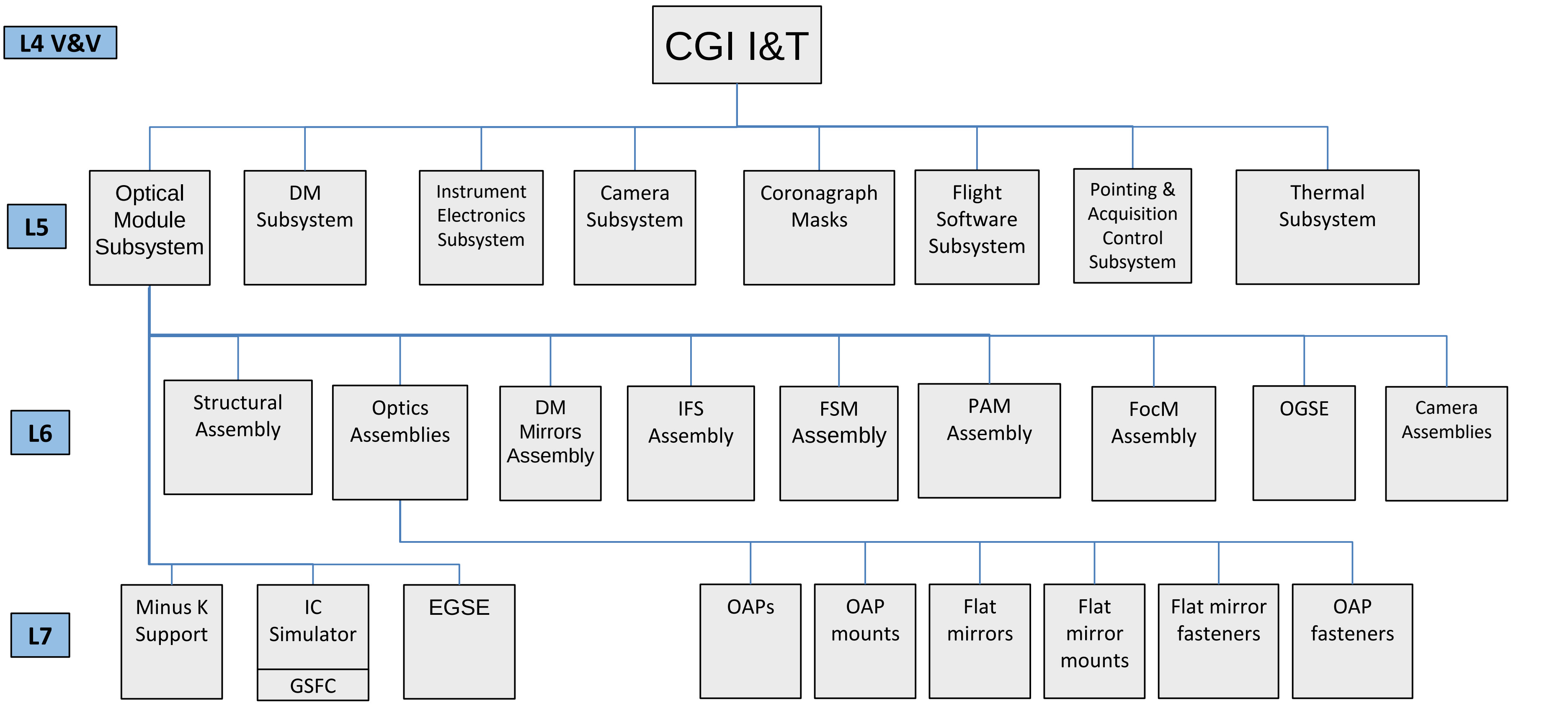
CGI CAD Model



CGI System Implementation



Optical Module Subsystem



Potential International Contributions

- EMCCDs
  - ESA/T-e2V
  - United Kingdom Space Agency/Center for Electronic Imaging of Open University
- Precision Alignment Mechanisms
  - DLR (*Deutsches Zentrum für Luft- und Raumfahrt e.V.)*/MPIA (Max Planck Institute for Astronomy)
- Off Axis Paraboloids
  - CNES (Centre National d’Etudes Spatiales)/Laboratoire Astrophysique Marseille
- Polarizers
  - Japan Aerospace Exploration Agency (JAXA)